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Effect of Site Class and Rainfall on Annual Range Response to Nitrogen and Phosphorus[1]

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Highlight

Maximum forage yield increases from application of fertilizer to annual range in southern California were in the following order according to site class: swale > gentle slope > open slope. The increase in forage yield per pound of applied nitrogen was greatest for low rates of nitrogen at the slope sites and for a much higher rate at the swale site. Residual effect of fertilizer on forage yield, measured the second and third year after application, partially compensated for a first-year lack of response at lower producing sites or during low rainfall years. Yield increase the second year after application of 60 lb. of nitrogen and 26 lb. of phosphorus per acre was 50% of the increase from the same application that year. Range site class and fertilizer residual effects are significant factors in fertilizer application programs on annual range in lower rainfall areas with high annual rainfall variability. Annual range soils that are deficient in available phosphorus by soil test require that the more limiting nitrogen deficiency be corrected before a forage yield response to phosphorus will be obtained.

Open annual range in California totals approximately 10 million acres (Talbot and Sampson, 1948). Seeds germinate with the beginning of winter rainfall and vegetation matures near the close of the rainfall season in the spring. Although annual rainfall distribution largely determines the type of grassland, annual amount is the principal factor determining dry matter production.

California mineral soils are inherently low in nitrogen. Forage yield response to nitrogen fertilizer application on range soils has been reported by many investigators (Hoglund et al., 1952; McKell et al., 1959; Jones, 1960; Jones and Evans, 1960; Woolfolk et al., 1962; Jones, 1963; and Conrad et al., 1966). Most of this research has been conducted in the coastal mountain areas of the central and northern parts of the state and in the foothills on the west side of the Sierra Nevada Mountains. Nitrogen application increases forage yield of annual range with winter rainfall in Australia (Rossiter, 1966) and Israel (Yitzchak and Seligman, 1969). According to Martin et al. (1958) application of nitrogen to annual range in California is an economically favorable practice.

Phosphorus deficiency on annual range in California is much less widespread than nitrogen deficiency. No response to phosphate fertilizers at inherent levels of available nitrogen were reported by Hoglund et al. (1952) and Jones (1963). Where nitrogen fertilizers were also applied forage yield increases from relatively high phosphorus applications were reported by McKell et al. (1959) and Jones and Evans (1960). Additional information on annual range response to phosphorus fertilizer was one of the objectives of this study.

Approximately 1.5 million acres of annual range are in the lower rainfall area of southern California. The coefficient of variation of annual rainfall is much higher in this area (Hershfield, 1962). Coefficients from 40 to 45% in southern California compare with 20 to 35% in other annual range areas. There was a need for determining range site effects on the response to fertilizer and the residual effect of applied fertilizer under these lower and less predictable water availability conditions.

Study Area and Procedures

Experimental sites were established in an area typical of annual range in the Santa Ana Mountains of the Coast Range. They were located on the Santa Rosa Ranch near Murrieta, California at an elevation of 2,000 feet. Sites were selected for the site class study according to the criteria of Bentley and Talbot (1951). This study was conducted at Sites No. 1, 2, and 3 (Table 1) in 1960. Residual fertilizer effects were studied at Sites No. 1 and 4 in 1962, and nitrogen and phosphorus effects were determined at all sites. Sites No. 1, 2, 3, and 4 were located within a radius of 1,000 feet while Site No. 5 was one-half mile from the others. Principal plant species at Sites No. 1, 2, 3, and 4 were wild oats (*Avena fatua*) and filaree (*Erodium botrys*). Other species were soft chess (*Bromus mollis*) and ripgut brome (*Bromus rigidus*). At Site No. 5 wild oats and filaree (*Erodium moschatum*) were dominant with lesser populations of bicolor lupine (*Lupinus bicolor*), bur clover (*Medicago hispada*), wild barley (*Hordeum leporinum*), and soft chess also present.

Experimental sites were fenced to exclude cattle. Fertilizer treatments were applied according to a randomized block design. Three or four replications were used depending on the area of uniform slope and soil. Plots were 30 or 25 ft × 10 ft, with the longer dimension oriented parallel to the slope direction. Fertilizers were applied between December 15 and January 7. Ammonium nitrate, treble superphosphate and gypsum were broadcast using a spreader with a positive feed mechanism. Urea and a resin-coated urea were also applied in a comparison of nitrogen fertilizers.

Dates of forage sampling ranged from March 31 to April 25 when vegetative growth was virtually complete. Forage in a central area 1.5 × 15 feet was clipped at a 2-inch height in each plot. Samples were dried to a constant weight at 65 C before weighing. Nitrogen content of the soil and the forage was determined by the micro-Kjeldahl method. Sodium bicarbonate extractable phosphorus (Olsen et al., 1954) was used as an estimate of available soil phos-

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Table 1. Experimental site characteristics.

Site No.	Site class	Slope (%)	Exposure	Soil: Type	Depth (ft)	Total N[1] (%)	Available P[1] (lb./acre)
1	Open, rolling slope	16	Southern	Perris v.f. sandy loam	3–4	0.11	8
2	Gentle slope	9	Western	Same as Site No. 1	>5	0.12	9
3	Swale	3	—	Same as Site No. 1	>5	0.14	11
4	Open, rolling slope	15	Western	Same as Site No. 1	3–5	0.12	9
5	Swale	<2	—	Twin Oaks clay loam	>6	0.17	14

[1] 0–6 inch soil depth.

phorus. Duncan's multiple range test was used to evaluate the significance of treatment effects.

Site Class Effects

Forage yields were highest at the swale site and least at the open slope site (Table 2). Rainfall for the 1959–60 season was 16.5 inches, below the long time average of 20.0 inches. Forage production at the swale site was twice that at the open slope site both without fertilizer and at the highest yield level with fertilizer. Forage increases from a high yielding treatment, 60 lb. of nitrogen and 26 lb. of phosphorus, were 1,140, 1,740, and 1,580 lb./acre for the open slope, gentle slope, and swale sites, respectively.

Where nitrogen alone was applied, the increase in yield per pound of nitrogen applied was greatest from the 30-lb. rate at the open slope and the gentle slope and from the 120-lb. rate at the swale. Phosphorus alone had no effect on yield at any site. However, combined with a nitrogen application there was a marked response to phosphorus especially at the gentle slope and swale sites. Sulfur applications, either alone or with nitrogen or nitrogen plus phosphorus had no effect on yield with the possible exception of the latter combination at the swale site.

Greater water deficiency at the open slope site is suggested as the major cause for the lower forage yield. Higher evapotranspiration on south facing slopes, greater potential for a runoff, and a shallower soil all support this explanation. More favorable water availability and somewhat greater inherent soil fertility probably were conducive to higher production at the swale site. These results indicate that relatively low rates of nitrogen application are more efficiently used on slope sites than high rates. In addition to requiring nitrogen applications, the most efficient response to phosphorus apparently will be obtained at range sites where other factors affecting yield potential such as water, are more favorable.

Residual Effect of Fertilizer

Since responses to fertilizer apparently were limited by water deficiency at the open slope site in 1960, observations for residual effects were made during the following two seasons. Rainfall for the 1960–61 season was 8.2 inches or less than half the long time average. Although vegetation on previously fertilized plots was darker green in color, dry matter production was negligible and yield

Table 2. Forage yield (lb./acre) responses to applications (lb./acre) of nitrogen, phosphorus, and sulfur at 3 sites, 1960.

Fertilizer applied N-P-S	Site class: Open slope site No. 1	Gentle slope site No. 2	Swale site No. 3
0-0-0	1,140 a[1]	1,540 a	2,320 a
30-0-0	1,660 ab	2,360 bc	2,480 a
60-0-0	1,920 ab	2,340 bc	2,580 a
120-0-0	1,940 ab	2,640 cd	3,440 bc
0-26-0	1,280 a	1,520 a	2,560 a
60-26-0	2,280 b	3,280 d	3,900 cd
0-0-60	1,180 a	1,820 ab	2,320 a
60-0-60	2,220 b	2,280 abc	2,880 ab
60-26-60	2,180 b	3,340 d	4,480 d

[1] Within a column, means followed by the same letter do not differ significantly at the 5% level.

Table 3. Forage yield (lb./acre) for the third year and the three-year period after fertilizer application (lb./acre).[1]

Fertilizer application N-P	Forage yield: 1962	Total 1960 & 1962
0-0	1,280 ab[2]	2,420 a
30-0	1,860 bc	3,520 b
60-0	2,560 d	4,480 c
120-0	2,240 cd	4,180 bc
0-26	1,080 a	2,360 a
60-26	1,720 bc	4,000 bc

[1] Open slope site, No. 1. Fertilizer applied prior to 1960 season. Little growth and no sampling the second year, 1961.

[2] Within a column, means followed by the same letter do not differ significantly at the 5% level.

Table 4. Forage yield (lb./acre) response to fertilizer (lb./acre), applied in December 1960, under highly variable annual rainfall.[1]

Fertilizer application N-P	Forage yield		
	1st year 1961	2nd year 1962	Total
0-0	320 a[2]	960 a	1,280 a
30-0	320 a	1,460 ab	1,780 ab
60-0	360 a	1,980 bc	2,340 bc
120-0	320 a	2,400 c	2,720 c
30-13	480 ab	1,340 ab	1,820 ab
60-13	480 ab	2,180 c	2,660 c
120-13	700 c	3,460 d	4,160 d
60-26	560 bc	2,540 c	3,100 c
120-26	680 c	4,240 de	4,920 ef
120-52	680 c	3,820 d	4,500 de
60-26	560 bc	2,540 c	3,100 c
60-26[3]	320 a	4,140 de	4,460 de
30-13, plus 30-13[3]	480 ab	3,640 d	4,120 d
120-26	680 c	4,240 de	4,920 ef
60-26, plus 60-0[3]	560 c	5,360 f	5,920 g
60-13, plus 60-13[3]	480 ab	4,800 ef	5,280 fg

[1] Site No. 4, rainfall 1960–61, 8.2 inches; 1961–62, 23.2 inches.
[2] Within a column, means followed by the same letter do not differ significantly at the 5% level.
[3] One initial and 3 additional applications were made in December 1961, prior to second year.

samples were not taken. Rainfall in 1961–62, the second season after fertilizer application, totalled 23.2 inches and forage production was relatively high (Table 3). Where 60 and 120 lb. of nitrogen had been applied two years earlier, greater yield increase was obtained than during the year of application (Table 2). Whereas 30 lb. was the most efficient rate of nitrogen during the season of application, residual effects increased the efficiency with the 60-lb. rate to a comparable level.

Residual effects were also great when rainfall was less than half the longtime average the year of fertilizer application and above average the second year (Table 4). Largest residual effects were measured for 60 and 120-lb. rates of nitrogen and for phosphorus in combination with 120 lb. of nitrogen. The two-year total increase in forage yield from one fertilizer application ranged from 500 lb./acre for 30 lb. of nitrogen to 3,640 lb./acre for 120 lb. of nitrogen and 26 lb. of phosphorus. One hundred percent of the former and 90% of the latter yield increase was a residual effect. Jones (1963) has reported a residual effect of nitrogen, but only at the 160-lb./acre rate. These results indicate that the residual effect of relatively low rates of fertilizer on production during the second and third year after application is an important consideration in planning a fertility program on annual range, especially in southern California.

Splitting a total of 60 lb. of nitrogen and 26 lb. of phosphorus equally between successive dry and wet years increased the yield a thousand pounds more than when the total amount was applied for the dry year and was nearly as effective as applying the total amount for the wet year (Table 4). Splitting the application of 120 lb. of nitrogen and 26 lb. of phosphorus equally between successive dry and wet years was not markedly better than applying the total amount for the dry year. However, applying all of the phosphorus for the dry year and splitting the nitrogen application was more effective than applying all of the fertilizer for the dry year. Greater yields but less efficient use of nitrogen was obtained with 120 lb. than with 60 lb. These results suggest that regular annual applications of between 30 and 60 lb. of nitrogen plus approximately 15 lb. of phosphorus may be optimum for forage production on open slope sites under the low and more variable rainfall of southern California. The need for annual applications of nitrogen is probably greater than the need for annual applications of phosphorus.

Phosphorus Effect

According to Olsen et al. (1954) yield response to phosphorus would be expected at the low levels of available phosphorus in these soils. The application of phosphorus fertilizer alone to range with no leguminous species did not affect yield. Forage yield responses to phosphorus fertilizer applied with nitrogen was obtained over a three-year period at four sites (Tables 2 and 4). Increasing the nitrogen rate to 120 lb./acre markedly increased the response to phosphorus (Table 4). These results contrast with those obtained by Hoglund et al. (1952), and Jones (1960 and 1963) which showed the nitrogen-phosphorus interaction on annual range to be generally insignificant. With an application of 150 lb. nitrogen and 87 lb. phosphorus per acre McKell et al. (1959) showed a large nitrogen-phosphorus interaction in forage yield.

With low seasonal water availability during 1961, phosphorus applied with nitrogen produced a statistically significant yield increase while nitrogen alone did not (Table 4). At the highest level of nitrogen, 120 lb./acre, these increases were over 100%, however, increases in dry matter averaged only 370 lb. The measurement of very small yield differences from the application of nitrogen alone was probably limited by the experimental procedure and site variability.

Fertilizer Effect on Species Contribution to Forage Yield

In a study of species contribution to forage yield the marked response of wild oats to increasing amounts of nitrogen was the most significant factor contributing to increases in total dry matter from fertilizer (Table 5). The dry matter yield of wild

Table 5. Forage yield (lb./acre) response of species to applications (lb./acre) of nitrogen and phosphorus.[1]

Fertilizer applied N-P	Forage yield					
	Filaree	Wild oats	Bicolor lupine	Bur clover	Other grasses & forbs	Total
0-0	2,440	540	420	240	740	4,380 a[2]
0-26	2,280	960	1,080	200	320	4,840 a
60-26	2,560	2,320	320	40	380	5,620 b
120-26	2,000	3,420	100	20	480	6,040 b

[1] Swale Site No. 5, 1962.
[2] Within this column, means followed by the same letter do not differ significantly at the 5%level.

oats was increased 1,360 and 2,460 pounds per acre by applications of 60 and 120 lb. of nitrogen, respectively. Increased grass yields as well as a relatively greater contribution of grasses to total forage yield had been reported by Jones (1963), Rossiter (1966), and Yitzchak and Seligman (1969).

Dry matter production of leguminous species, present at Site No. 5, was reduced by the nitrogen applications. Where phosphorus alone was applied, bicolor lupine comprised 22% of the total forage yield. The additional application of 60 and 120 lb. of nitrogen reduced the lupine component of the total forage to 6 and 2%, respectively. Inasmuch as bicolor lupine is of low palatability to animals, its reduction by nitrogen application was considered desirable. Bur clover, which comprised only a small portion of the total dry matter, was also markedly reduced by nitrogen application. Jones (1963) and Yitzchak and Seligman (1969) reported reductions in the leguminous component of annual range vegetation by nitrogen application. In this study filaree yield was not affected by fertilizer application and its contribution to total yield became relatively less as yields increased.

In a comparison of ammonium nitrate, urea and resin-coated urea for forage yield at Site No. 5 in 1962, no differences among fertilizers were recorded at 30-lb. and 60-lb. rates of nitrogen. At the 120-lb. rate resin-coated urea was superior to the other nitrogen carriers, suggesting that slow release forms of nitrogen may increase efficiency of nitrogen use with high application rates at swale sites.

Table 6. Nitrogen content (%) of forage with fertilizer application (lb./acre) on three sites, 1960.

Fertilizer applied N-P	Nitrogen content		
	Open slope site No. 1	Gentle slope site No. 2	Swale site No. 3
0-0	1.78	2.22	2.01
30-0	2.33	2.04	1.91
60-0	2.98	2.37	2.25
120-0	3.31	2.49	2.58
60-26	3.14	2.20	2.01

Table 7. Nitrogen content (%) of specie forage with nitrogen and phosphorus application (lb./acre).[1]

Fertilizer applied N-P	Nitrogen content				
	Wild oats	Legume species[2]	Filaree	Other species	Total forage
0-0	1.51	3.47	1.58	1.72	1.82
0-26	1.28	3.17	1.92	1.58	2.01
60-26	1.18	3.05	1.68	1.41	1.51
120-26	1.16	2.67	1.90	1.48	1.45

[1] Swale Site No. 5, 1962.
[2] Bicolor lupine and bur clover.

Nitrogen Content of Forage

The effect of nitrogen fertilizer application on nitrogen content of forage differed with site class (Table 6). All rates of nitrogen increased nitrogen content at the open slope site. At the gentle slope and swale sites the 30-lb. rate did not increase nitrogen content and increases at higher rates of nitrogen application were smaller than at the open slope site. The total uptake of nitrogen (product of percent content in Table 6 and yield in Table 2), was similar for a given nitrogen rate at all sites. Apparently, where growing conditions were more favorable, greater increases in growth from nitrogen application diluted the nitrogen content of forage to lower values than were obtained at the open slope site.

A reduction in nitrogen content of forage with the application of fertilizer was measured at a swale site in 1962 (Table 7). Increases in wild oats production from the combined applications of nitrogen and phosphorus (Table 5), largely accounted for the decreased nitrogen content of the total forage. The increase in wild oats growth not only decreased the nitrogen content of wild oats forage but also markedly increased the wild oats contribution to total dry matter both of which tended to reduce nitrogen content of the total forage. Phosphorus application alone increased nitrogen content of forage by stimulating growth of bicolor lupine (Table 5), with its inherently higher nitrogen content.

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